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(71) Applicant (*for all designated States except US*): COMSAT CORPORATION [US/US]; 6560 Rock Spring Drive, Bethesda, MD 20817 (US).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): BECKER, Neal, D. [US/US]; 6810 Falstone Drive, Frederick, MD 21702 (US).

(74) Agents: CUSHING, David, J. et al.; Sughrue, Mion, Zinn, MacPeak & Seas, Suite 800, 2100 Pennsylvania Avenue, N.W., Washington, DC 20037-3202 (US).

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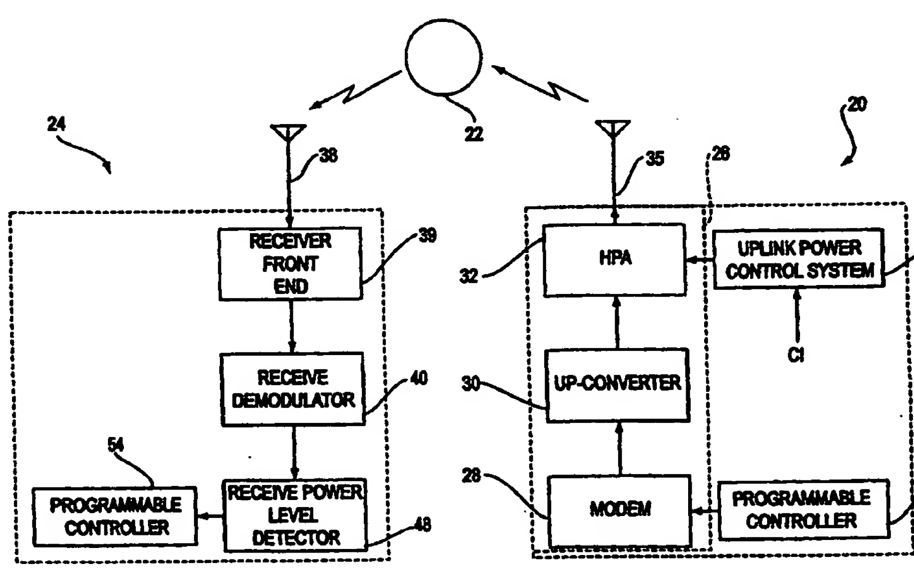

(57) Abstract

A method for controlling power output by a sender station (20) in an RF communications system that includes at least the sender station (20) and a receiver station (24), by periodically transmitting a calibration signal from the sender station (20) to the receiver station (24), and, at the receiver, deducing a prescribed power transfer characteristic (e.g., the AM/AM power transfer curve of an uplink high power amplifier within a transmit chain) of the sender station, based on the calibration signal. The deducing step is carried out by measuring a receive power level of each calibration signal of a set of different transmitted calibration signals. The method includes further steps of determining a maximum acceptable operating point of the uplink high power amplifier based upon the deduced power transfer characteristic and then adjusting the operating point as required.

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POWER OUTPUT CONTROL SYSTEM FOR RF COMMUNICATIONS SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates generally to power control systems for RF communications systems, and, more particularly, to a system and method for controlling the power output of earth stations in a satellite communications network.

This application is based on and claims priority from provisional patent applications, Serial Nos. 60/064,673, 60/062,497 and 60/062,496, which are incorporated herein by reference for all purposes.

The typical satellite uplink (ground equipment or earth station) includes a modem, upconverter, and high power amplifier (HPA), that are oftentimes collectively referred to as the "transmit chain". The total gain of the transmit chain is typically quite high, e.g., 60 dB or greater. Each component in the transmit chain will experience gain variations over time, temperature, and frequency. U.S. Patent Nos. 4,500,984, 4,462,001 and 4,606,285, which patents are incorporated herein by reference for all purposes, describe several aspects of the background in which the invention was made.

In certain applications, such as small, low-cost earth stations, these gain variations become quite significant. More particularly, to keep the cost of the ground equipment to a minimum, such earth stations are typically equipped with an HPA that is as small as possible, and that is

operated close to saturation, as opposed to using a larger HPA and operating it at a backoff point that provides a comfortable margin of safety (e.g., 3 dB to 6 dB below the 1 dB compression point). Because the HPA is operated close to saturation, and because gain variations are not well-controlled with low-cost ground equipment, the gain variations in the transmit chain become quite significant, as will become evident from the following discussion.

When the HPA is operated close to saturation, the modulated signal (e.g., a QPSK or BPSK signal) will suffer from spectral regrowth (except in the special case of certain constant-envelope modulation techniques, which have other drawbacks). This spectral regrowth, which is also commonly referred to as sidelobe regrowth, can cause interference to adjacent carriers or services. The maximum interference permitted in most satellite communications systems is strictly regulated, with the consequence that spectral or sidelobe regrowth limits are commensurately strictly regulated. Thus, for this reason, gain variations in a transmit chain in which the HPA is operated close to saturation becomes quite significant.

Additionally, high frequency (e.g., Ku band) satellite uplinks suffer from rain fades. The most common technique for combating rain fade is to employ a larger HPA and/or antenna in order to allow for sufficient extra operating margin in the link. However, this technique is expensive, particularly for such applications as small, low-cost earth stations.

Another technique for combating rain fades and gain variations is to employ uplink power control, by which the ground HPAs are operated at a lower power except when extra power is needed to overcome uplink signal fading due to rain fade and/or gain variation.

An inherent problem with uplink power control is that there must be some mechanism to ensure that the gain is not increased beyond a point that will cause unacceptable spectral regrowth, i.e., spectral regrowth that exceeds the specified spectral regrowth limits for the satellite communication system. There are two presently known methods for controlling the uplink power output in such a manner as to ensure that the gain is not increased beyond a point that will cause unacceptable spectral regrowth.

The first method for controlling the uplink power output in such a manner as to ensure that the gain is not increased beyond a point that will cause unacceptable spectral regrowth is to employ an HPA that is larger than is necessary for a given application, to thereby provide an operating margin that is sufficiently large to ensure that the gain will never have to be increased beyond a point that would cause unacceptable spectral regrowth, i.e., the HPA will never have to be driven close enough to saturation to meet the power output requirements for any operating conditions. Of course, this method is expensive because the cost of a larger HPA operated at a comfortable backoff point is much greater than the cost of a smaller HPA operated close to saturation.

The second method for controlling the uplink power output in such a manner as to ensure that the gain is not increased beyond a point that will cause unacceptable spectral regrowth is to accurately calibrate the HPA power or gain. Accurate calibration is also an expensive proposition. Measuring the output power of the HPA, which is a subset of accurate calibration, is also expensive, since such measurements introduce some power loss, thereby necessitating a larger HPA.

Based on the above and foregoing, it can be appreciated that there presently exists a need in the art for a system and method for controlling the uplink power output in a satellite communications system that overcomes the drawbacks and shortcomings of the presently available technology. More particularly, there presently exists a need in the art for a relatively low-cost system and method for controlling the power output of the uplink HPA in such a manner as to avoid driving the uplink HPA into saturation despite gain variations over time, temperature, and frequency. The present invention fulfills this need in the art by periodically determining, at the receiver, the power transfer characteristics (power in versus power out or AM/AM characteristics) of the uplink HPA for the current operating conditions, and then using this information to periodically determine the operating point of the uplink HPA that constitutes the maximum gain setting or operating point of the uplink HPA that will avoid driving the uplink HPA into saturation under the current operating conditions. Since, in a satellite communications system, in most instances, the major source of nonlinearity is the uplink HPA, any nonlinearity that is

detected at the receiver will be primarily attributable to the uplink HPA.

SUMMARY OF THE INVENTION

The present invention encompasses a method for controlling power output by a sender station in an RF communications system that includes at least the sender station and a receiver station, by periodically transmitting a calibration signal from the sender station to the receiver station, and then, at the receiver station, deducing a prescribed power transfer characteristic of the sender station, based upon the calibration signal. In a presently contemplated exemplary embodiment, the prescribed power transfer characteristic is a prescribed power transfer characteristic (e.g., the AM/AM power transfer curve) of an uplink high power amplifier within a transmit chain of the sender station, the RF communications system is a satellite communications system, and, the calibration signal comprises a set of calibration signals transmitted by the sender station with each calibration signal within the set having a different respective power level known to both the sender station and the receiver station. In this exemplary embodiment, the deducing step is carried out by measuring a receive power level of each calibration signal within each set of calibration signals transmitted by the sender station, and the method further includes the steps of determining a maximum acceptable operating point of the uplink high power amplifier based upon the deduced power transfer characteristic of the uplink high power amplifier, and then adjusting the operating point of the uplink high power amplifier, as required, based upon the results of the determining step, in order to prevent the operating point of the uplink high power amplifier from exceeding the maximum acceptable operating point.

The present invention also encompasses a sender station power output control system for use in an RF communications system that includes at least the sender station and a receiver station, in which the sender station power output control system includes circuitry that transmits a calibration signal from the sender station to the receiver station, and circuitry, at the receiver station, that deduces a prescribed power transfer characteristic of the sender station, based upon the calibration signal. In a presently contemplated exemplary embodiment, the prescribed power

transfer characteristic is a prescribed power transfer characteristic (e.g., the AM/AM power transfer curve) of an uplink high power amplifier within a transmit chain of the sender station, the RF communications system is a satellite communications system, and, the calibration signal comprises a set of calibration signals transmitted by the sender station with each calibration signal within the set having a different respective power level known to both the sender station and the receiver station. In this exemplary embodiment, the circuitry that deduces is operable to deduce the prescribed power transfer characteristic of the uplink high power amplifier by measuring a receive power level of each calibration signal within each set of calibration signals transmitted by the sender station. Further, in this exemplary embodiment, the sender station power output control system also includes circuitry that determines a maximum acceptable operating point of the uplink high power amplifier based upon the deduced power transfer characteristic of the uplink high power amplifier, and circuitry that adjusts the operating point of the uplink high power amplifier, as required, based upon the determinations made by the circuitry that determines, in order to prevent the operating point of the uplink high power amplifier from exceeding the maximum acceptable operating point.

BRIEF DESCRIPTION OF THE DRAWINGS

These and various other features and aspects of the present invention will be readily understood with reference to the following detailed description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a block diagram of a satellite communications system that incorporates the uplink power output control method and system of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will first be described in general methodological terms, and will then be described in terms of an exemplary implementation of this general methodology in a generic satellite communications system. As will become readily apparent to those having ordinary skill in the pertinent art, the present invention is not limited to any particular application, environment, or implementation, but rather, may have utility in a broad spectrum of different

applications, environments, or implementations.

In broad terms, the present invention encompasses the basic methodology of periodically transmitting a calibration signal from a first (sender/transmit) station whose power output is to be controlled, to a second (receiver/receive) station, and then using the calibration signal received at the second station to deduce the power transfer characteristics of a transmit signal amplifier within the first station. Preferably, the power level of the calibration signal is variable. The deduced power transfer characteristics of the transmit signal amplifier can then be used to determine a maximum safe or acceptable gain setting or operating point of the transmit signal amplifier for the current operating conditions. Thus, the operating point of the transmit signal amplifier can be dynamically adjusted as required to ensure that prescribed modulated or transmitted signal characteristics (e.g., spectral or sidelobe regrowth characteristics) are maintained within an acceptable range. At a minimum, the uplink power control system can be prevented from increasing the operating point or gain setting of the transmit signal amplifier beyond the determined maximum safe or acceptable point or setting, even when such an increase is determined to be necessary in order to compensate for signal fading, e.g., due to rain and/or gain variations.

It is presently contemplated that the methodology of the present invention will find particular utility in the context of a satellite communications system having small, low-cost sending and receiving earth stations, in which it is necessary or desirable to ensure that the uplink HPA within the transmit chain of the sending station is not driven into saturation, despite dynamically changing conditions (e.g., variable rain fade and other variable channel characteristics) and despite gain variations of the transmit equipment over time, temperature, and frequency, in order to thereby ensure that the spectral regrowth of the modulated signal will not exceed specified spectral regrowth limits. Preferably, a set of calibration signals will be transmitted by the sending station at varying power levels, in a prescribed or pre-programmed pattern known to both the sending and receiving station, to thereby enable the receiver station to deduce the power transfer characteristics of the uplink HPA with sufficient accuracy to determine the maximum safe or acceptable operating point or gain setting of the uplink HPA for the current

operating conditions. At a minimum, the uplink power control system can be prevented from increasing the operating point or gain setting of the transmit signal amplifier beyond the determined maximum safe or acceptable point or setting, even when such an increase is determined to be necessary in order to compensate for signal fading, e.g., due to rain and/or gain variations.

With reference now to FIG. 1, there will now be described an exemplary implementation of the present invention within a satellite communications system that includes a sender station 20 that uplinks an RF modulated signal (e.g., a QPSK or BPSK signal) to a satellite transponder 22 that in turn downlinks the RF modulated signal to a receiver station 24.

The sender station 20 includes an uplink transmit chain 26. The uplink transmit chain 26 includes a modem 28, an upconverter 30, and a high power amplifier (HPA) 32. The modem 28 produces at its output an RF modulated signal to be transmitted to the receiver station 24 via the satellite transponder 22. The upconverter 30 upconverts the RF modulated signal output by the modem 28 to the frequency band of the satellite communications channel that it is to be transmitted over. The HPA 32 increases the power level of the RF modulated signal to a suitable level for transmission by a transmit antenna 35 via the satellite uplink. The sender station 20 also includes an uplink power control system 37 that functions to adjust a gain setting or operating point of the HPA 32 in response to a control input CI.

The receiver station 24 includes a receive dish or antenna 38 that receives the RF modulated signal via the satellite downlink, and a receiver front end 39 that amplifies, conditions, and downconverts the received RF modulated signal, and produces at its output an RF modulated signal. The receiver station 24 also includes a receive demodulator 40 that demodulates the RF modulated signal and produces, at its output, a demodulated signal that is further processed and utilized in a known manner, e.g., to produce a cable television signal that is transmitted via coaxial cable to subscriber households.

In accordance with an exemplary embodiment of the present invention, the sender station

20 includes a programmable logic device, e.g., a programmable controller 44, that is programmed to cause the uplink transmit chain 26 to periodically transmit a set of calibration signals at varying power levels in a prescribed or pre-programmed pattern known to both the sender station 20 and the receiver station 24. Additionally, the receiver station 24 includes a receive power level detector 48 that is programmed to measure the receive power level by any suitable technique. One technique for measuring the receive power level is to obtain an AGC reading from the receive demodulator 40. On digital links, a carrier-to-noise (C/N) ratio or bit error rate (BER) indication could also be used for this purpose if the AGC reading was not available.

In accordance with this exemplary embodiment, the receiver station 24 also includes a programmable logic device, e.g., a programmable controller 54, that is programmed to determine the power transfer characteristics of the uplink HPA 32 based upon a correlation of the measured receive power level information obtained from the receive power level detector 48 for each of the received calibration signals with the pre-programmed calibration signal power levels. For example, the programmable controller 54 can be easily programmed to construct an AM/AM or power transfer curve (plotting power in versus power out). The major source of any nonlinearity, in most cases, will be the uplink HPA 32, so that the power transfer curve is primarily representative of the power transfer curve of the uplink HPA 32. Of course, the receive power level measurements may be averaged and/or additional/other noise reduction and signal processing techniques may be employed in order to increase the precision and accuracy of the deduced power transfer characteristics of the uplink HPA 32.

In order to enable the gain variations of the uplink HPA 32 to be tracked in real-time, and thereby prevent the uplink HPA 32 from being overdriven (i.e., beyond the maximum safe operating point), despite varying channel quality variations (e.g., due to rain) and gain variations over time, temperature, and frequency, it is preferable that the calibration signals be transmitted at a periodic interval that is shorter than the interval over which gain variations over time, temperature, and frequency occur, and/or that the determination of the power transfer characteristics of the uplink HPA 32 be made at periodic intervals that are shorter than the interval over which gain variations over time, temperature, and frequency occur. In most cases,

the gain variations over time, temperature, and frequency are relatively slow, so that the periodic interval between successive sets of calibration signals (and/or the periodic interval between successive uplink HPA power transfer characteristic determinations) can be relatively long. For example, in a typical satellite communications system, an hourly interval should suffice.

It should also be noted that the determination or measurement of the power transfer characteristic (e.g., AM/AM characteristic) of the uplink HPA 32 is independent of any gain variations in the transmit or receive equipment, since it is a relative rather than an absolute measurement. The only requirement is that the measurements of the receive power level for successive calibration signals at different respective power levels be performed at a rate that is substantially faster than the rate of gain variations, to thereby ensure that the variation in gain will be small between the measurements of the receive power level for successive calibration signals at different respective power levels. Thus, it is preferable that the calibration signals at different respective power levels within each set of calibration signals be transmitted at a rate much higher than the rate of gain variations, so that the magnitude of the gain variation between successive measurements of the receive power level of the respective calibration signals within each set will be kept small. On the other hand, some averaging of the results of successive measurements can be used to reduce the signal variations due to other sources, such as rain fade, so that one erroneous or anomalous reading is not instantly acted upon. In general, well-known statistical signal processing techniques may be employed to maximize the accuracy and to minimize the probability of errors and anomalies.

Either the programmable controller 54 within the receiver station 24 or other processing circuitry within the receiver station 24 or other processing circuitry within the sender station 20 (e.g., the uplink power control system 37) may be utilized to determine the maximum safe or acceptable gain setting or operating point of the uplink HPA 32, for the current operating conditions, based upon the deduced power transfer characteristics of the uplink HPA 32 determined by the programmable controller 54. In the event processing circuitry within the receiver station 24 (e.g., programmable controller 54) makes the determination of the maximum safe level of operation of the uplink HPA 32, this information must, of course, be transmitted to

the sender station 20 to enable the gain setting or operating point of the uplink HPA 32 to be adjusted, as required. In any event, the uplink power control system 37 is preferably programmed to adjust the gain setting or operating point of the uplink HPA 32, as required, based upon these determinations of the maximum safe level of operation of the uplink HPA 32, to thereby provide a type of closed-loop control over the operating level of the uplink HPA 32, so that overdriving of the uplink HPA 32 can be prevented, despite gain variations over time, temperature, and frequency.

Although an exemplary and presently preferred embodiment of the present invention has been described in detail hereinabove, it should be clearly understood that many variations and/or modifications of the basic inventive concepts taught herein which may appear to those skilled in the pertinent art will still fall within the spirit and scope of the present invention as defined in the appended claims.

WHAT IS CLAIMED IS:

1. A method for controlling power output by a sender station in an RF communications system that includes at least the sender station and a receiver station, the method including the steps of:

periodically transmitting a calibration signal from the sender station to the receiver station; and,

at the receiver station, deducing a prescribed power transfer characteristic of the sender station, based upon the calibration signal.

2. The method as set forth in Claim 1, wherein the calibration signal has a power level that is variable.

3. The method as set forth in Claim 1, wherein the prescribed power transfer characteristic comprises a prescribed power transfer characteristic of a transmit signal amplifier within the sender station.

4. The method as set forth in Claim 3, wherein the transmit signal amplifier comprises a high power amplifier.

5. The method as set forth in Claim 3, wherein:

the RF communications system comprises a satellite communications system; and,

the transmit signal amplifier comprises an uplink high power amplifier.

6. The method as set forth in Claim 1, wherein the calibration signal comprises a set of calibration signals transmitted by the sender station with each calibration signal within the set having a different respective power level known to both the sender station and the receiver station.

7. The method as set forth in Claim 3, further including the step of determining a

prescribed operating point of the transmit signal amplifier based upon the deduced power transfer characteristic of the transmit signal amplifier.

8. The method as set forth in Claim 7, further including the step of adjusting the operating point of the transmit signal amplifier, as required, based upon the results of the determining step.

9. The method as set forth in Claim 5, further including the step of determining a maximum acceptable operating point of the uplink high power amplifier based upon the deduced power transfer characteristic of the uplink high power amplifier.

10. The method as set forth in Claim 9, further including the step of adjusting the operating point of the uplink high power amplifier, as required, based upon the results of the determining step, in order to prevent the operating point of the uplink high power amplifier from exceeding the maximum acceptable operating point.

11. The method as set forth in Claim 1, wherein the deducing step is carried out by measuring a receive power level of the calibration signal.

12. The method as set forth in Claim 6, wherein the deducing step is carried out by measuring a receive power level of each calibration signal within each set of calibration signals transmitted by the sender station.

13. The method as set forth in Claim 1, wherein:

the prescribed power transfer characteristic comprises a prescribed power transfer characteristic of an uplink high power amplifier within a transmit chain of the sender station;

the RF communications system comprises a satellite communications system; and,

the calibration signal comprises a set of calibration signals transmitted by the sender station with each calibration signal within the set having a different respective power level known to both the sender station and the receiver station.

14. The method as set forth in Claim 13, wherein the deducing step is carried out by measuring a receive power level of each calibration signal within each set of calibration signals transmitted by the sender station.

15. The method as set forth in Claim 14, further including the step of determining a maximum acceptable operating point of the uplink high power amplifier based upon the deduced power transfer characteristic of the uplink high power amplifier.

16. The method as set forth in Claim 15, further including the step of adjusting the operating point of the uplink high power amplifier, as required, based upon the results of the determining step, in order to prevent the operating point of the uplink high power amplifier from exceeding the maximum acceptable operating point.

17. In an RF communications system that includes at least a sender station and a receiver station, a sender station power output control system, including:

means for periodically transmitting a calibration signal from the sender station to the receiver station; and,

means, at the receiver station, for deducing a prescribed power transfer characteristic of the sender station, based upon the calibration signal.

18. The sender station power output control system as set forth in Claim 17, wherein:

the prescribed power transfer characteristic comprises a prescribed power transfer characteristic of an uplink high power amplifier within a transmit chain of the sender station;

the RF communications system comprises a satellite communications system; and,

the calibration signal comprises a set of calibration signals transmitted by the sender station with each calibration signal within the set having a different respective power level known to both the sender station and the receiver station.

19. The sender station power output control system as set forth in Claim 18, wherein

the deducing means is operable to deduce the prescribed power transfer characteristic of the uplink high power amplifier by measuring a receive power level of each calibration signal within each set of calibration signals transmitted by the sender station.

20. The sender station power output control system as set forth in Claim 19, further including means for determining a maximum acceptable operating point of the uplink high power amplifier based upon the deduced power transfer characteristic of the uplink high power amplifier.

21. The sender station power output control system as set forth in Claim 20, further including means for adjusting the operating point of the uplink high power amplifier, as required, based upon the determinations made by the determining means, in order to prevent the operating point of the uplink high power amplifier from exceeding the maximum acceptable operating point.

22. In an RF communications system that includes at least a sender station and a receiver station, a sender station power output control system, including:

circuitry that transmits a calibration signal from the sender station to the receiver station; and,

circuitry, at the receiver station, that deduces a prescribed power transfer characteristic of the sender station, based upon the calibration signal.

23. The sender station power output control system as set forth in Claim 22, wherein:

the prescribed power transfer characteristic comprises a prescribed power transfer characteristic of an uplink high power amplifier within a transmit chain of the sender station;

the RF communications system comprises a satellite communications system; and,

the calibration signal comprises a set of calibration signals transmitted by the sender station with each calibration signal within the set having a different respective power level known to both the sender station and the receiver station.

24. The sender station power output control system as set forth in Claim 23, wherein the circuitry that deduces is operable to deduce the prescribed power transfer characteristic of the uplink high power amplifier by measuring a receive power level of each calibration signal within each set of calibration signals transmitted by the sender station.

25. The sender station power output control system as set forth in Claim 24, further including circuitry that determines a maximum acceptable operating point of the uplink high power amplifier based upon the deduced power transfer characteristic of the uplink high power amplifier.

26. The sender station power output control system as set forth in Claim 25, further including circuitry that adjusts the operating point of the uplink high power amplifier, as required, based upon the determinations made by the circuitry that determines, in order to prevent the operating point of the uplink high power amplifier from exceeding the maximum acceptable operating point.

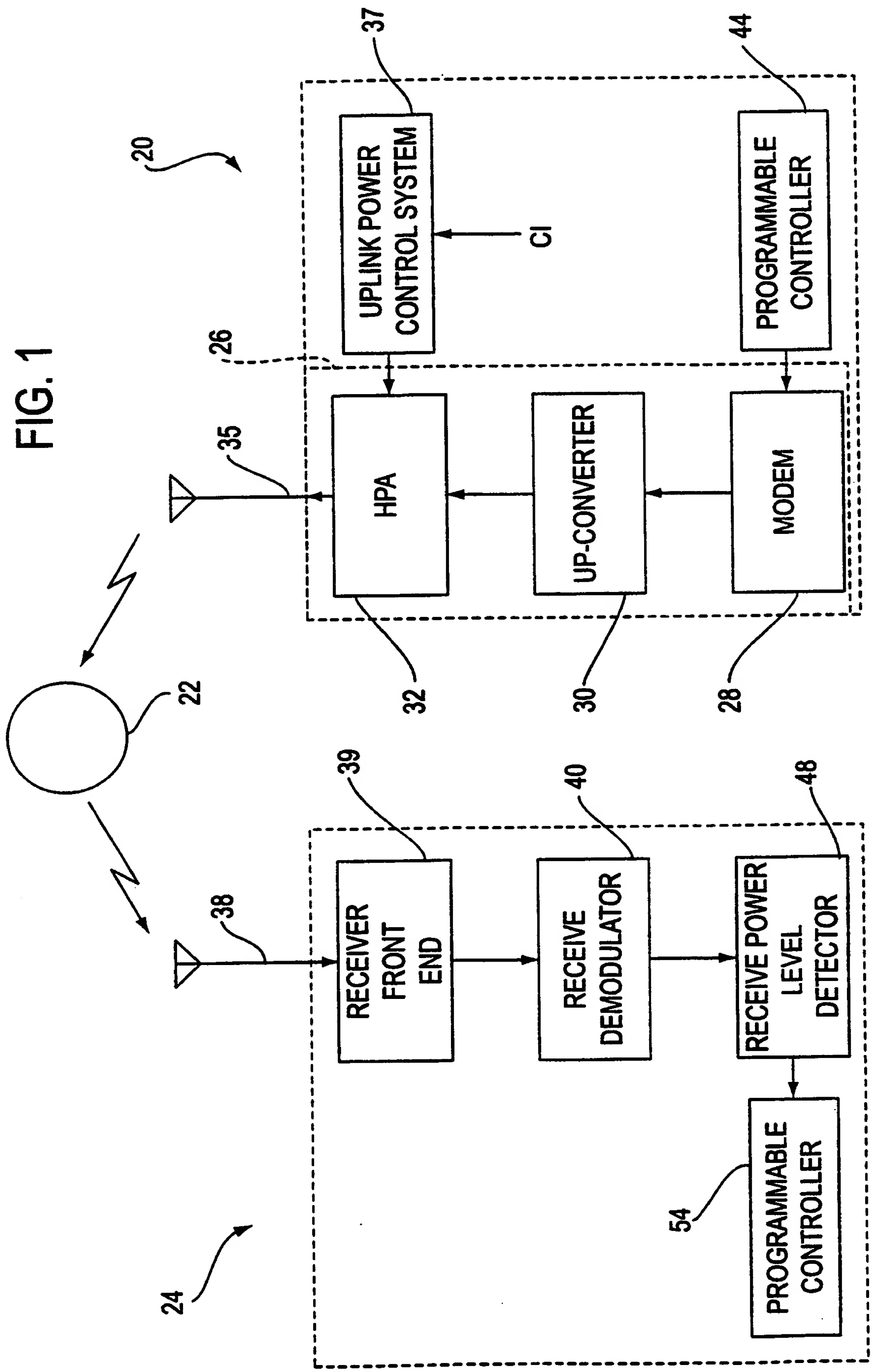

FIG. 1

SUBSTITUTE SHEET (RULE 26)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/21633

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H04B 7/00
US CL :455/13.4, 522, 115
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/13.4, 522, 115, 67.1, 67.4, 69, 126, 127

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,868,795 A (MCDAVID et al.) 19 September 1989, col. 4, lines 30-44, col. 5, lines 1-16 and 33-50, col. 11, lines 12-29 and col. 11, line 45 through col. 12, line 29.	1-26
X	US 5,678,208 A (KOWALEWSKI et al.) 14 October 1997, col. 2, lines 53-64 and col. 3, lines 36-47.	1-3, 17, 22
X,P	US 5,732,328 A (MITRA et al.) 24 March 1998, col. 9, lines 5-53 and Fig. 5.	1-3, 17, 22
A	US 4,228,538 A (SCHARLA-NIELSEN et al.) 14 October 1980.	1-26
A,P	US 5,754,942 A (WACHS) 19 May 1998.	1-26

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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Date of the actual completion of the international search	Date of mailing of the international search report
29 DECEMBER 1998	25 MAR 1999
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer LES KINCAID Joni Hill Telephone No. (703) 306-3016

INTERNATIONAL SEARCH REPORT

International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	US 5,748,037 A (ROZENTAL et al.) 05 May 1998.	1-26
A	US 5,603,106 A (TODA) 11 February 1997.	1-26